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ON BRAZIL'S PARTICIPATION IN THE FIRST TEN YEARS OF THE INPRO PROJECT AND PERSPECTIVES AHEAD

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ABSTRACT

In September 2001, the International Atomic Energy Agency (IAEA) launched the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) to help ensure that nuclear energy is available to contribute to meeting the world energy needs of the 21st century in a sustainable manner. To achieve its objective INPRO brings together technology holders and technology users to consider jointly the international and the national actions to achieve the desired innovations in nuclear reactors, fuel cycles and institutional approaches. This paper reviews INPRO's main achievements in its first ten years of existence and highlights Brazil's contributions to the project and the benefits gained from its membership. Among INPRO's main achievements are the development of the INPRO assessment methodology, key studies and collaborative project results, and the establishment of the Dialogue Forum between technology holders and technology users. Brazil contributed to the project by providing a cost-free expert to the INPRO Coordination Group in 2002, by performing an assessment of two small sized reactors for deployment in the country using INPRO methodology published in 2009, and by participating in two collaborative projects related to technology innovations, which shall be completed by the end of this year. The paper concludes with a short presentation of the opportunities for the country's participation in the activities of the INPRO Action Plan for the biennium 2012-2013, currently under preparation.

1. INTRODUCTION

In the last decades, growing concerns over energy resource availability, energy security and climate change suggested an important role for nuclear in supplying sustainable energy in the 21st century. In response to these concerns, the International Atomic Energy Agency (IAEA) launched in September 2001 the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) to help ensure that nuclear energy is available to contribute to meeting the world energy needs of the 21st century in a sustainable manner. In 1987, the Brundtland report of the World Commission on Environment and Development [1] defined sustainable development as *"the development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* and identified four essentials dimensions: economic, social, environmental and institutional. The *economic dimension* encompasses the requirements of strong and durable economic growth, such as preserving financial stability and a low and stable inflation rate. The *environmental dimension* requires eliminating or reducing negative externalities that are responsible for the depletion of natural resources and environmental degradation. *Social sustainability* emphasises the importance of equity among various groups of population, of adaptability to major demographic changes, of stability in social and cultural systems, of democratic participation in decision-making, etc. A fourth dimension in attaining sustainability is the development of an *institutional* *infrastructure,* since appropriate legal and policy instruments are required to encourage and implement sustainable development.

To achieve its major objective INPRO brings together technology holders and technology users to consider jointly the international and the national actions to achieve the desired innovations in nuclear reactors, fuel cycles and institutional approaches. Membership in INPRO is open to IAEA Members States and recognised organisations provided that they make a contribution to the project. Contributions can be made by donating extra budgetary funds, providing cost-free experts, performing and work package (i.e., performing assessment studies using INPRO methodology or participating in Collaborative INPRO Collaborative Projects). By 2010, INPRO membership had grown to 31 members and the European Commission representing 75 percent of the world's GDP and 65 percent of the world population. Brazil joined INPRO in 2002. Since its establishment, INPRO has found continued and strong support from IAEA Member States through resolutions of IAEA's General Conferences and from world leaders.

In support of its objective, INPRO is collaborating with other international initiatives and institutions including the Generation IV International Forum (GIF), the European Commission (EC), the World Nuclear Association (WNA), the Organisation for Economic Cooperation and Development's Nuclear Energy Agency (OECD/NEA) and the European Sustainable Nuclear Energy Technology Platform (SNETP). The aim is to ensure good synergy, coordination of activities and avoid duplication of efforts.

Over the first 10 years INPRO has evolved in accordance with the developments in nuclear science and with the changing interests of its Member States. In its initial phase, named – INPRO Phase 1 – the project focussed on developing a holistic methodology to assess innovative nuclear energy systems (INSs) against multiple criteria for sustainability (INPRO programme area A), INPRO started in 2006 a second phase – INPRO Phase 2 – concentrated largely in four additional programme areas, including definition of different options and scenarios for the global and regional development of nuclear energy over the next 50 years (programme area B), considerations of innovations in nuclear technology (programme area C), considerations of innovations in institutional arrangements (programme area D), and the dialogue forum on nuclear energy innovations (programme area E). The management of INPRO, including strategic programme planning, organisation of meetings, policy coordination with other initiatives, and effective communication with INPRO stakeholders is encompassed in the cross-cutting programme area F.

This paper reviews INPRO's main achievements in its first ten years of existence and highlights Brazil's contributions to the project and the benefits gained from its membership. Among INPRO's main achievements are the development of the INPRO assessment methodology; key studies and collaborative project results, and the establishment of the Dialogue Forum between technology holders and technology users. Brazil contributed to the project by providing a cost-free expert to the INPRO Coordination Group in 2002, by performing an assessment of two small sized reactors for deployment in the country using INPRO methodology published in 2009 and by participating in two collaborative projects related to technology innovations, which shall be completed soon. All these contributions are briefly reviewed in this work. The paper concludes with a short presentation of the opportunities for the country's participation in the activities of the INPRO Action Plan for the biennium 2012-2013, currently under preparation.

2. INPRO FIRST 10 YEARS: MAIN ACHIEVEMENTS

Among INPRO's main achievements are the development of the Assessment Methodology, the Joint Study for the assessment of nuclear energy systems (INSs) based on closed nuclear fuel cycle with fast reactors, the investigation of the global architecture of INSs based on thermal reactors and fast reactors with closed fuel cycles, the initiation and completion of Collaborative Projects on issues relevant to innovative and evolutionary systems, and the establishment of the Dialogue Forum. These contributions are reviewed in the following:

2.1. Assessment Methodology

The INPRO methodology has been developed for screening an innovative nuclear system (INS), for comparing different INSs to find a preferred one consistent with the sustainable development of a given State, and for identifying the research, development and demonstration needed to improve the performance of existing components of an INS and/or to develop new components. An INS encompasses all nuclear facilities of the front and back end of a nuclear fuel cycle, i.e., mining/milling, conversion, enrichment, fuel fabrication, reactor, reprocessing and materials management (including transportation, storage and waste management), together with all related institutional measures, such as legal framework, regulatory bodies, etc. A full scope nuclear energy system assessment evaluates the complete lifecycle of the facility, i.e., design, construction, operation, decommissioning and waste disposal.

The INPRO methodology identifies a set of basic principles, user requirements and criteria in a hierarchical manner as the basis for the assessment of an INS. The highest level in the INPRO hierarchy is a basic principle, which is a statement of a general goal that is to be achieved in an INS. The second level is a user requirement that sets out the measures to be taken (mostly by the designers/developers but also by owners/operators and government institutions) to meet the general goal of the corresponding basic principle. On the third level of hierarchy, to verify whether the user requirements have been properly met, the assessor of the INS uses a criterion. Thus, it is intended that (bottom-up approach):

- The fulfilment of a criterion for an INS is confirmed by the indicator(s) complying with the acceptance limit(s);
- The fulfilment of a user requirement(s) is confirmed by the fulfilment of the corresponding criterion (criteria);
- The fulfilment of a basic principle is achieved by meeting the related user requirement(s).

In a number of cases, the acceptance limits are based on comparison of the value of an indicator for an INS with the value of an existing design, which shall be understood as the mean state-of-the-art designs with at least one plant in commercial operation as of 2004. Sometimes, acceptance limits are defined in terms of compliance with current regulations, which shall be understood to mean regulations in effect at the time the assessment is performed. For some indicators, internationally agreed values for the associated acceptance limits are proposed.

INPRO takes a holistic approach to assess innovative nuclear energy systems in seven areas, namely, economics, safety, waste management, environment, proliferation resistance, physical protection and infrastructure. The basic principles of each area are stated below:

Economics: The basic principle in the area of economics requires that to contribute to sustainable development, energy and related products and services from an INS must be affordable and available. If energy and related products and services are to be affordable, the cost to the consumer must be competitive with that of low cost/priced alternatives. If they are to be available, the systems to supply them must be developed and deployed.

Safety: The basic principles in the area of safety of nuclear installations require that the INS enhance the concept of defence-in-depth, with an increased emphasis on inherent safety characteristics and passive safety features resulting in a health and environmental risk of an INS that is comparable with that of industrial facilities used for similar purposes.

Waste Management: The basic principles in the area of waste management have been derived from the IAEA safety fundamentals concerning the principles of radioactive waste management (IAEA, 2006b). Thus, the generation of waste is to be kept to the minimum level practicable, securing an acceptable level of protection of human health and the environment without undue burdens on future generations, and all waste generation and waste management steps are to be taken into account.

Environment: INPRO has set out two basic principles related to the environment, one dealing with the acceptability of environmental effects caused by nuclear energy and the second dealing with the capability of an INS to deliver energy while making efficient use of non-renewable resources.

Proliferation resistance: The basic principles associated with proliferation resistance require that intrinsic features and extrinsic measures be implemented throughout the full life cycle of the INS, and that they be optimised, by design and engineering, to provide cost effective proliferation resistance.

Physical protection: In the area of physical protection only one basic principle has been defined by INPRO. It requires the implementation of an adequate physical protection regime throughout the lifetime of an INS.

Infrastructure: The basic principle concerning infrastructure states that regional and international arrangements are to provide alternatives that enable any country that so wishes to adopt an INS for the supply of energy and related products without making an excessive investment in national infrastructure.

If all criteria, user requirements and basic principles are met in the assessment areas, the nuclear energy system assessed represents a source of energy consistent with a country's sustainable development criteria. If not all components are met, a given nuclear energy system may still represent an excellent interim energy supply system, but will need to change and evolve to become sustainable in the longer term.

The INPRO methodology is documented in a nine volume publication, *Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems: INPRO Manual – Overview of the INPRO Methodology* [2] and in a new publication, *Introduction to the Use of the INPRO Methodology in a Nuclear Energy System Assessment* [3].

Using the INPRO Methodology, six national INPRO nuclear energy system assessment (NESA) studies have been performed by individual countries, including Brazil, and one NESA study was conducted jointly by eight countries. The lessons learned front these NESA studies provide an important feedback for the improvement of the methodology and are documented in the publication *Lessons Learned from Nuclear System Assessments (NESA) Using the INPRO methodology* [4].

2.2. The Joint Study

The Joint Study, initiated by the Russia Federation, was started in 2005 and completed in 2007. Seven other INPRO members participated in the study that had the objectives of assess an INS based on a closed nuclear fuel cycle with fast reactors (CNFC-FR) for compliance with INPRO criteria of sustainability, determine milestones for the INS deployment, and establish frameworks for, and areas of, collaborative research and development (R&D) work.

The joint Study was implemented in several steps. First, experts analysed the country/region/world data, discussed national and global scenarios for introducing the INS CNFC-FR, identified technologies suitable for the INS, and broadly defined a common INS CNFC-FR. In the second step, the study examined the characteristics of the INS CNFC-FR for compliance with INPRO criteria. It was agreed to use as a reference system a near term INS CNFC-FR based on proven technologies, such as sodium coolant, MOX pellet fuel and aqueous reprocessing technology. The main results and findings of the study can be summarised as following:

- Although the safety characteristics of near term INS CNFC-FR are considered to be in compliance with INPRO criteria, further study is required to achieve a lower risk of severe accidents;
- In some countries, the introduction of fast reactors might contribute to na efficient use of nuclear fuel resources by increasing the use of plutonium fuels and denatured uranium fuel, to be generated in the fast reactor blankets, if needed;
- The INS CNFC-FR has the potential to meet all the today's requirements of waste management. By developing and introducing novel technologies for na optimal management of nuclear fissile products and minor actinides, the INS CNFC-FR would have the potential for a "break-through" in meeting sustainability requirements related to waste management;
- Due to the intrinsic, i.e., technological features of the CNFC-FR, its proliferation resistance could be comparable to, or higher than, that of a once-through fuel cycle (OTFC). The INS is a key technology for the balanced use of fissile materials. The Joint Study concluded that the intrinsic features of this INS offer a unique technology platform for meeting the basic principles of sustainability in the area of proliferation resistance. Further developing extrinsic measures, e.g., implementation of safeguard agreements and additional protocols in force, would facilitate the transition to a new a higher level of nuclear power proliferation resistance;
- A CNFC-FR requires a regional or multilateral approach to front and back end fuel cycle services and the transition to a global nuclear architecture;
- The design of currently operating nuclear energy systems with CNFC-FR will not meet economic requirements. The Joint Study showed that simplifying the design, increasing the fuel burn-up and reducing costs by R&D along with small series of constructions,

would make the costs of nuclear power plants with fast reactors comparable to those of thermal reactor and fossil fuelled power plants.

The Joint Study is documented in the publication *Assessment of Nuclear Energy Systems Based on a Closed Nuclear Fuel Cycle with Fast Reactors* [5].

2.3. Collaborative Projects

The IAEA coordinate and support several INPRO Collaborative Projects (INPRO CPs) identified by INPRO Members to a commonly study enabling technologies and approaches to topics of major interest. Collaborative projects under IAEA/INPRO auspices can be carried out using one of the following options: Coordinated Research Project (CRP), Technical Cooperation Project (TCP) and Joint Initiative (JI), which are funded mainly by the INPRO members participating in each project. INPRO CPs can be grouped in the following categories: scenarios and nuclear energy development, nuclear safety, proliferation resistance, technical challenges in reactor technologies, and environment and infrastructure. Fourteen CPs proposed as JI were endorsed by the INPRO Steering Committee in 2007 and are now concluded or expected to be concluded this year. Examples of Collaborative Projects are:

Global Architecture of INS based on Thermal and Fast Reactors including Closed Fuel Cycles (GAINS) (*Scenarios and nuclear energy development*)**.** This project aims to identify ways of enhancing sustainability features of national nuclear systems through technical innovations and multilateral cooperation. A coherent vision for the evolution of a nuclear energy system requires unification of a methodological simulation platform and validation of the simulation results through sample analysis of transition strategies from the present to the future nuclear power systems, including assessment of financial, environmental and proliferation risks.

Proliferation Resistance: Acquisition/Diversion Pathways Analysis (PRADA). The overall objective of this project was to provide guidance on enhancing the proliferation resistance of INSs and to contribute to strengthening the assessment area of proliferation resistance of the INPRO methodology. The project focused on identifying and analysing high level pathways for the acquisition or diversion of fissile material for a nuclear weapons programme, using the DUPIC (Direct Use of Spent PWR Fuel in CANDU) DUPIC fuel cycle as a case study with an assumed diversion scenario. This project was concluded at the end of last year (2010).

Investigation of Technological Challenges related to the Removal of Heat by Liquid Metal and Molten Salt Coolants from Reactor Cores Operating at High Temperature (COOL). This project investigates the technological challenges of cooling reactor cores that operate at high temperatures in advanced fast reactors, high temperature reactors and accelerator driven systems by using liquid metal and molten salts as coolants. COOL addresses two fields of research regarding liquid metals and molten salts as coolants: experimental investigations and computational fluid dynamics studies on thermohydraulics; and thermophysical properties, coolant chemistry and interaction between coolant and structure materials.

Environmental Impact Benchmarking Applicable for Nuclear Energy Systems under Normal Operation (ENV). Protection of the environment is a central theme within the concept of sustainable development and many predictive tools exist to assess the environmental impact of different nuclear facilities. In general, this project aims to compare existing methodologies available for assessing environmental impact of nuclear energy systems under normal operation and provide feedback for the practical application of the INPRO methodology in the area of environment.

2.4. Dialogue Forum

The objective of the INPRO Dialogue Forum is to bring together technology holders and technology users from all interested IAEA Member States and foster information exchange so that technology holders can understand the needs and concerns of technology users, and users can better understand the possibilities and limitations of technology holders associated with the development and deployment of innovative nuclear energy systems (INSs). The Dialogue Forum involves a variety of stakeholders, including governments, national and international organisations, regulators, vendors, operators and researchers. It is an opportunity for sharing information without necessarily reaching a consensus or adopting joint policies. In fact, open discussions between technology holders and users at an early stage of development of nuclear energy systems facilitates harmonisation of practices, establishment of strategic partnerships and the future deployment of INSs.

The first two INPRO Dialogue Forums were held at IAEA headquarters in Vienna in February and October 2010, respectively. The first one addressed socio- and macroeconomic factors, proven technology, and safety approaches for nuclear energy development and deployment. Key recommendations from this workshop included:

- Develop a methodology to assess the maturity/readiness of innovative nuclear technologies;
- Advance further discussion on innovative business models that could facilitate deployment of innovative nuclear technologies through risk sharing;
- Extend harmonisation efforts to include the security and safety-security interface, waste management and transportation of nuclear material.

The second Dialogue Forum addressed multilateral approaches to nuclear energy deployment with a focus on institutional challenges. Traditionally, the focus of multilateral cooperation has been the nuclear fuel cycle (front and back end). However, the meeting explored other key areas were multilateral cooperation is crucial if nuclear energy is going to live up to its potential, such as:

- Multilateral approaches to safety, licensing and regulation;
- Financing issues in multilateral approaches to nuclear energy development;
- Multilateral approaches in prototypes and demonstration of innovative technologies.

The third workshop of the INPRO Dialogue Forum, scheduled for October 2011, will focus discussion on technology-users' considerations for small and medium-sized reactors (SMRs). The purpose of the workshop is discuss user considerations in the light of the conclusions reached in a previous two-year study on common user considerations [6], which served as a basis for the first dialogue forum, and recent developments in SMR technologies.

3. BRAZIL'S PARTICIPATION IN THE FIRST 10 YEARS OF INPRO

Brazil joined INPRO in 2002 and at the same year nominated a cost-free expert for the project for 3 months (Gaianê Sabundjian from the Nuclear Energetic Research Institute, IPEN/CNEN). In 2003, Brazil nominated a delegate to represent the country in INPRO Steering Committee (Benedito Baptista Filho, from IPEN/CNEN; replaced by this author in 2004). Two years later, Brazil started an assessment study of two small sized reactors for deployment in the country using INPRO methodology, which was completed in 2008. In the following year, Brazil started its participation in two INPRO Collaborative Projects related to technology innovations, which are expected to be completed soon. These contributions are briefly reviewed in the following:

3.1. National Assessment Study

In 2005, Brazil submitted a working package for further participation in INPRO consisting of the assessment of two small and innovative nuclear reactors, the *International Reactor Innovative and Secure (IRIS)* and the *Fixed Bed Nuclear Reactor (FBNR)*, using INPRO methodology. Three major driven forces stood behind the Brazilian proposal at that time:

- First, the ongoing review of the Brazilian nuclear programme, which included, in the highest scenario, the construction of new nuclear power stations in the country's Southeast and Northeast regions;
- Second, Brazil's membership in the international consortium for development of IRIS. IRIS is a modular, integral type, pressurised, light water cooled, small power reactor with a conventional refuelling scheme;
- Third, the development of FBNR conceptual design at the Federal University of Rio Grande do Sul (UFRGS), Brazil. FBNR is a modular, integral type, pressurised, light water cooled, factory (re)fuelled, small power reactor (70 MWe per module) without on-site refuelling.

The objective of the work was to perform a *screening (not comparative) assessment* of the IRIS and FBNR reactors as components of a potential INS, which includes a conventional open fuel cycle based on enriched uranium using INPRO methodology. A comparative assessment between these two INS components was not attempted mainly because the two reactor designs were in a very different stage of development.

The main scope of the study was the assessment of the IRIS and FBNR reactors. The front and back-end technologies of the open fuel cycle option selected were not assessed, but the inflow and outflow of materials in the reactor component were considered, whenever possible. The scope of the assessment study was further limited to the areas which were of the country's main interest – safety and economics, in the IRIS case – or areas in which the INS has an estimated greater potential - safety and proliferation resistance, in the FBNR case. To complete the assessment study, feedback on the application of the INPRO methodology was offered. Also the research and development required for the improvement of the reactors studied were also included whenever applicable.

The reference reactor for this assessment study was the pressurised light water reactor Angra 2 (Admiral Álvaro Alberto Nuclear Power Station, Unit 2), located at Itaorna, Angra dos Reis municipality in the State of Rio de Janeiro.

The results of the assessment of the IRIS and FBNR reactors are summarised below in accordance with the terminology introduced in the INPRO Manual: if the value of the indicator is acceptable, the judgement is that the INS *complies with* or *has potential* to fulfil the specific criterion assessed. Otherwise, the judgement becomes *non-compliant* or *no potential* for this criterion. This judgement procedure is repeated likewise for all criteria of a user requirement, then for all user requirements of a basic principle and finally for all basic principles of a methodology area:

INS based on IRIS reactor: The advanced stage of development of the design of the International Reactor Innovative and Secure – IRIS and the availability of the most of the data of interest allowed the execution of a reasonably detailed assessment of this INS component:

- In the reactor safety area, the results indicated that IRIS reactor complies with most of the user requirements and has potential to fulfil the corresponding basic principles. This fact confirmed the initial expectations produced by IRIS safety-by-design philosophy;
- In regard to the area of economics, IRIS compares favourably with the large PWR nuclear power plants currently operated in the country.

Overall these assessment results indicate that IRIS innovative design complies mostly with the basic principles of reactor safety and economics areas of INPRO methodology.
INS based on FBNR reactor: The FBNR project is in an initial stage of development and therefore some of INPRO indicators could be evaluated qualitatively only:

- With regard to the reactor safety area the relatively high percentage of *acceptable* results in the performed judgement indicates that, despite the project's low level of maturity, the FBNR innovative design is compliant with most of the Basic Principles of the reactor safety area of INPRO methodology;
- Regarding proliferation resistance, the results indicate that all indicators are in principle acceptable. Therefore the FBNR preliminary design has high potential to effectively comply with the Basic Principle of this area of INPRO methodology.

Overall these assessment results indicate that the FBNR innovative design has potential to comply mostly with the Basic Principles of reactor safety and proliferation resistance areas of INPRO methodology.

The rationales for the judgement on the potential of the INS reactor component (IRIS and FBNR) for each of the methodology areas appraised are documented in full detail in reference [7]. A summary of the study, together with other six national assessment studies are documented in the IAEA publication [4] cited before.

The assessment of the IRIS reactor was performed by experts (E. T. Palmieri, C. V. G. de Azevedo, M. A. Veloso, B. C. Neiva and I. D. Aronne) from the Centre of Nuclear Technology Development (CDTN) at the State of Minas Gerais, by experts (G. Sabundjian and D. A. de Andrade) from the Nuclear and Energetic Research Institute (IPEN), located at São Paulo, and by this author from the Nuclear Engineering Institute (IEN), at Rio de Janeiro. All three research institutes belong to the Research and Development Directorate (DPD) of the National Nuclear Energy Commission (CNEN). The FBNR was assessed by expert (F. Sefidvash) from the Federal University of Rio Grande do Sul (UFRGS) with support of some international collaborators. CNEN's Directorate of Research and Development (DPD) provided general support, and this author contributed to, co-ordinated the work and edited the report.

3.2. Collaborative Projects

Since 2008 Brazil participates in 2 INPRO Collaborative projects, namely, *Investigation of Technological Challenges related to the Removal of Heat by Liquid Metal and Molten Salt Coolants from Reactor Cores Operating at High Temperature (COOL)* and *Environmental impact benchmarking applicable for nuclear energy systems under normal operation (ENV),* which were briefly introduced in Section 2.3. Here, the project's overall objectives and specific research scopes are further described and the national contributions outlined.

3.2.1. Project COOL

This project covers cooling of reactor cores operating at high temperature up to 1000ºC with a focus on liquid metals and molten salts as coolants, advanced fast reactors and accelerator driven systems.

Specific research scopes are to establish the properties of high temperature coolants; validate computational fluid dynamics and neutronics codes; address various issues related to handling of high temperature coolants; compatibility of components in intimate contact with high temperature coolants, and monitor and control high temperature coolant chemistry.

Brazil investigates, numerically, the kinetics of an accelerator driven system (ADS) during startup transients and the behaviour of a fuel pin of a typical hexagonal core of ADS using heat transient correlations. These activities are performed by an expert (R. S. Santos) from IEN/CNEN.

The project COOL is nearing completion. The final report of the project is now being prepared and it will be published by IAEA in 2012. Detailed information of the project can be found at INPRO Collaborative Projects WebPages at Internet [8].

3.2.2. Project ENV

This project compares existing methodologies available for assessing environmental impacts of nuclear energy systems under normal operation (accident scenarios are not considered). The focus of the study is on testing an approach that uses one source term, namely a nuclear power plant at normal operation, three release scenarios (release to atmosphere, to surface water and to marine water) and the impact on humans as the target group. Three case studies have being undertaken: in the first one, all parameters such as meteorological data, transfer coefficients, exposure pathways, and consumption rates were predefined; in the second case , atmospheric releases were studied, using the same fixed parameters but varying only the meteorological data to see how local data would affect the ranking of radionuclides; preliminary results indicate that the use of local meteorological data does not significantly change the ranking of radionuclides. Finally, the third case study included diverse natural and cultural living conditions, such as country specific food chains; here, preliminary results indicate that these variations do have an effect radionuclide ranking, particularly in terms of the type of consumed food.

In short, results expected of this project include a benchmark on an assessment methodology to rank radionuclides according to their degree of health impact on humans, a comparison of the most important radionuclides in terms of environmental impact for a given source term, reference scenarios for INPRO methodology in the area of environment and feedback on the practical application of INPRO methodology for environment protection.

Brazil's activities related to project ENV are carried out by an expert (L. de Molnary) from IPEN/CNEN.

The project ENV is expected to be completed by middle of 2012. The final report of the project is being prepared and shall be published as an IAEA document later that year or at the beginning of 2013. Detailed information of the project can be found at INPRO Collaborative Projects WebPages at Internet [9].

3.3. Dialogue Forum

Brazil has participated in the first two workshop of the INPRO Dialogue Forum, which were held at IAEA headquarters in Vienna last year (see Section 2.4). The first Brazilian attendees came from IEN/CNEN and Eletrobrás Termonuclear S/A, a government-controlled company responsible for building and operating thermal nuclear power plants in Brazil. It is expected and desirable that representatives of other stakeholders of the Brazilian nuclear sector, including the Academia, may also participate in future dialogue forums.

3.4. Steering Committee

In addition to participating in INPRO activities, representatives of INPRO members also form the INPRO Steering Committee, the advisory body that guides the project activities. The Committee meets regularly to review ongoing progress and to provide guidance in future activities. Every two years the Steering Committee discusses and endorses the INPRO Action Plan, which defines detailed task areas and priorities for implementing INPRO activities taking into account the financial and human resources available.

Brazil participated in 13 out of 17 ordinary meetings of the INPRO Steering Committee (SC) since the launching of the project in 2001. This author has been the national delegate to the INPRO Steering Committee since 2004.

4. BENEFITS OF BRAZIL'S MEMBERSHIP IN INPRO

Over its first 10 years of existence, lNPRO has made an outstanding progress, including the development of a methodology for the assessment of the sustainability potential of innovative nuclear energy systems, the implementation of a framework for carrying out collaborative research projects on technological and institutional innovations in nuclear energy, and the creation of a dialogue forum for bringing together technology holders and technology users to consider jointly the actions required to achieve the desired innovations. These are the results of INPRO's work that had the greatest positive impacts in Brazil, as reported in the following paragraph.

In Brazil, lNPRO methodology was first used to judge the potential of two innovative small-sized pressurised reactors as alternative options to satisfy the expansion of nuclear power predicted in the National Energy Plan 2030, the government's long-term plan for energy development in the next two decades. Participation in two lNPRO collaborative projects in its turn was an excellent and challenging opportunity for Brazilian engineers and researchers to share knowledge and contribute to the development of innovative nuclear technologies. Although only recently established, the first two INPRO dialogue forums have promoted interesting and useful discussions of issues that are relevant for the expansion of nuclear power in Brazil such as, socio-economic factor influencing the development and deployment of nuclear energy and the issue of when innovative technology can be considered proven enough to be select for deployment in developing countries.

5. PERSPECTIVES AHEAD

During the 54th IAEA General Conference in September 2010, the Agency celebrated INPRO’s 10th anniversary with a festive ceremony and a technical briefing. The latter consisted of a series of invited talks on the future of nuclear innovations. This included innovative eco-nuclear reactors that would contribute to sustainable global energy supply, transmutation issues of generation IV reactors, a forum to stimulate knowledge innovation for nuclear energy, and a focus on innovation to deliver commercially viable nuclear energy. The event ended with a panel discussion with participants from INPRO members who shared views and visions about the future role of INPRO. One important issue discussed was whether or not it was one of INPRO’s roles to foster/perform technological research and development in large scale. France and United States of America argue that this is not the case, since it conflicts with the IAEA’s mandate, but other countries, like Russia and Brazil, believe that it is up to INPRO members to decide what level of research and development work that are willing and prepare to perform under INPRO auspices. In fact, Russia proposed to the interested member states to launch an initiative for the development of a multilateral cooperation research and development (R&D) programme on fast reactors. Russia’s representative stated, furthermore, that “in future we are ready to consider a possibility to use the Multifunctional Fast research Reactor to be constructed for such multilateral and bilateral cooperation”. With regard to this issue it is worth mentioning that up to now all INPRO collaborative projects were carried out as joint initiatives, which means that they are entirely funded by the participating INPRO countries.

These issues were further elaborated by INPRO Steering Committee in its 17th meeting held in May 2011 at IAEA headquarters. This Steering Committee meeting was in fact the second in a series of three planning meetings that is developing and adopting the INPRO Action Plan for 2012 and 2013. The meeting also charted the way forward by discussing a vision and strategy for the medium term, i.e. over the next five years to 2016. A vision for INPRO’s development over the next five years is based on the project’s contribution to global nuclear energy sustainability. The proposed pathway goes from understanding the challenges through studies and analysis of a sustainable nuclear energy system to developing options for technical and institutional innovations through Collaborative Projects to implementing solutions by assisting member states in planning and deciding on their long-range nuclear energy strategies.

The nuclear accident at the Fukushima Dai-Ichi nuclear power plants in March 2011 and its impact on the future on nuclear activities was also discussed at the meeting. It was generally recognised that despite this unfortunate accident in Japan the underlying drivers for nuclear power still remain. While nations need a secure energy supply and are committed to reduce greenhouse gas emission, nuclear energy has a role to play. INPRO in turn has a strong role to play in ensuring that nuclear energy production is sustainable with the understanding that there is a need to continue to strengthen aspects related to safety and security.

While it is foreseen that some of the current activities will continue, a number of new and follow up projects were proposed and are at discussion. Other areas of interest expressed by SC delegates included an update of the INPRO methodology (together with a simplified description of its current version to allow for better understanding by new users and its use as an educational tool in human resource development), global nuclear energy scenarios, thorium as a resource, small and medium sized reactors and public outreach as a Dialogue Forum topic.

The draft version of Action Plan 2012-2013 strategic planning and the possibilities for Brazil's further participation in INPRO are discussed below:

5.1. Action Plan 2012-2013

INPRO's activities in the next biennium will be reorganised in four stable core areas (Projects):

- Project 1: National long range nuclear energy strategies
- Project 2: Global nuclear energy scenarios
- Project 3: Technological and institutional innovations
- Project 4: Policy and Dialogue Forum

Currently there are 21 activities under consideration by INPRO members for inclusion in the action plan: 8 activities in Project 1, 5 activities in Project 2, and 4 activities in Projects 3 and 4. Brazil is considering participating in a new Joint Study (JS) in Project 1 area, a Collaborative Project (CP) in Project 3, and should continue to participate in the project's Steering Committee and Dialogue Forum on Global Nuclear Energy Sustainability, activities that are included in Project 4 area. A brief description of the Joint Study and Collaborative Project of Brazil's possible interest is presented in the following:

Joint Study on Spent Nuclear Fuel and Radioactive Waste Management in national, Regional and Global Scale. Assessment of Options using INPRO Methodology. The objectives of this study are three-fold: first, the joint (thorium and thorium uranium) assessment of spent nuclear fuel (SNF) and radioactive waste (RW) management options (including multilateral approaches) in national, regional (and possibly global levels) using INPRO methodology with special emphasis on newcomer's needs. Secondly, identify required research, development and demonstration (RD&D) and institutional measures, and establish frameworks for their implementation to achieve the desired options, and thirdly to develop technical reports and/or guidance for assessing national SNF and RW management and providing recommendations in back-end for policy makers.

Collaborative project to Investigate Options for a New Project on Collaborative Fast Reactor, Fuel Cycle and Materials R&D (using the MBIR or international network): The objective of this preliminary study is to identify options for implementation of joint research projects on fast reactor technology using in future the Multifunctional Fast Research Reactor (MBIR) to be constructed by Russian Federation and/or other international network of laboratories worldwide. The idea is to offer INPRO members a possibility to carry out multilateral and bilateral cooperation research and development programme on fast reactors and associated fuel cycle technologies, including thorium and uranium minerals.

The complete action plan of 2012-2013 activities shall be finalised and adopted at the 18th meeting of the INPRO Steering Committee in November 2011.

5. CONCLUSIONS

Since its inception in 2001, the lNPRO project has made an outstanding progress. INPRO's activities are centred on the key concept of *global nuclear energy sustainability* and have made a positive impact on most of the participant countries, including Brazil.

In this author's viewpoint, INPRO offers an excellent opportunity for Brazilian researchers, engineers and technicians alike to contribute effectively to the development of technological and institutional innovations in nuclear energy through bilateral and multilateral cooperation. With due account for the main concerns of the Brazilian Nuclear Programme (PNB) and for CNEN's priority projects (such as, the design, construction, licensing and commissioning of a *Multipurpose Research Reactor,* and the *Development of Recipients for Transportation and Storage of Irradiated Fuels*), the national research groups working in nuclear energy science and technology (including the National Institute of Science and Technology for Innovative Reactors, established in 2009) should be encouraged to participate more extensively in INPRO's activities, mainly in INPRO's collaborative projects.

When it comes to the question of which innovative technology to support developing, some comments are in order, accounting for the selected technology possible contribution to the sustainable energy (electricity) production in the country in the future. First, as mentioned earlier, INPRO should concentrate its efforts in the coming years on the development of fast reactors and associated fuel cycles (see Section 5.1). This priority follows as a consequence of the results of the Joint Study on closed fuel cycles with fast reactors (see Section 2.2). Secondly, the technology roadmap [10] developed by the Generation IV International Forum (GIF), a technology-oriented activity by technology holders, already identified, back in 2003, the sodium-cooled fast-reactor system as the generation IV system closest to completion. Finally, Brazil, in its turn, has some experience and expertise in fast reactor technology mainly through the implementation of CNEN's Fast Reactor Programme at the Institute of Nuclear Engineering [11] during the 70's and 80's (the programme is currently halted awaiting decision of the Ministry of Science and Technology on its continuation, reformulation or phase out), and through CNEN's membership in IAEA Technical Working Group on Fast Reactors since 1988 [12]. Based on the above considerations, in this author's viewpoint, a *new and well-structured* research programme on *innovative sodium-cooled fast reactors* (possibly with once-through fuel cycle) would serve as a cluster structure to integrate the national research groups working on nuclear science and technology around an innovative reactor and fuel cycle technology that should be available for deployment in 2030 (according to the expectations of the GIF's initiative).

Hence, this author would like to conclude by suggesting Brazil (CNEN) to consider engaging in two new INPRO collaborative projects proposed for the INPRO Action Plan 2012-2013, namely: the ***Collaborative project to Investigate Options for a New Project on Collaborative Fast Reactor, Fuel Cycle and Materials R&D (using the MBIR or international network),*** and the ***Joint Study on Spent Nuclear Fuel and Radioactive Waste Management in National, Regional and Global Scale. Assessment of Options using INPRO Methodology****, (see Section 5.1).*

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